Deeply Virtual Compton Scattering off ^{4}He

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(On behalf of the CLAS collaboration)

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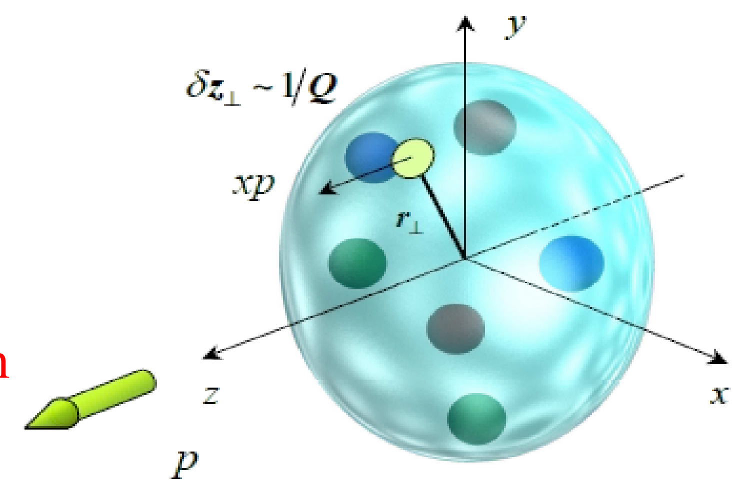
Physics Motivations

◊ Form factors:

→ Contain information on the quarks transverse spatial distributions
→ They are accessible via elastic scattering

◊ Parton distribution functions:

→ Provide the quarks longitudinal momentum distributions
→ Reachable via deep inelastic scattering



◊ Generalized parton distributions (GPDs):

- Contain information on:

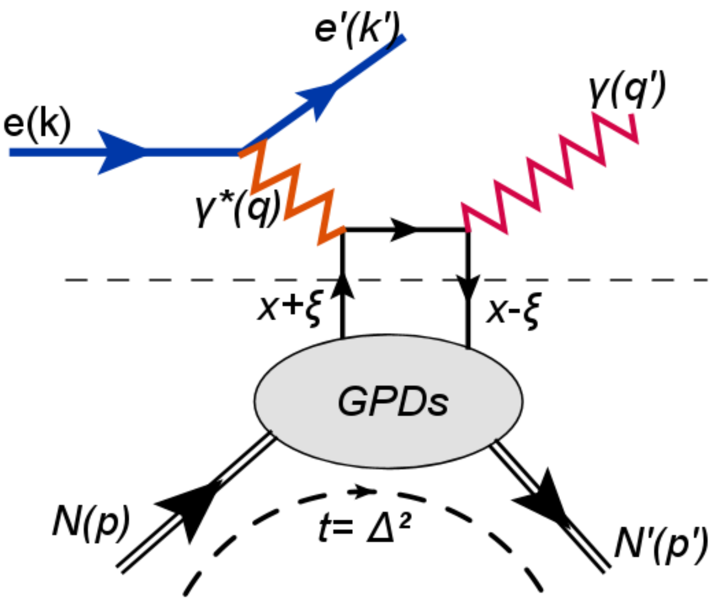
→ Quark/anti-quark correlations
→ Correlations between longitudinal momentum and transverse spatial position of partons

- Accessed via exclusive processes:

→ Deeply Virtual Compton Scattering (DVCS)
→ Deeply Virtual Meson Production (DVMP)

From the theoretical point of view, the DVCS is considered the cleanest way to access the GPDs

DVCS Reaction



Hard part (perturbative, calculable in PQCD)

Factorization

Soft part (Non-perturbative, parameterized in terms of GPDs)

t : transfer momentum
ξ : skewdness parameter
x : longitudinal parton momentum ($x \neq x_B$)
Q^2: photon's virtuality

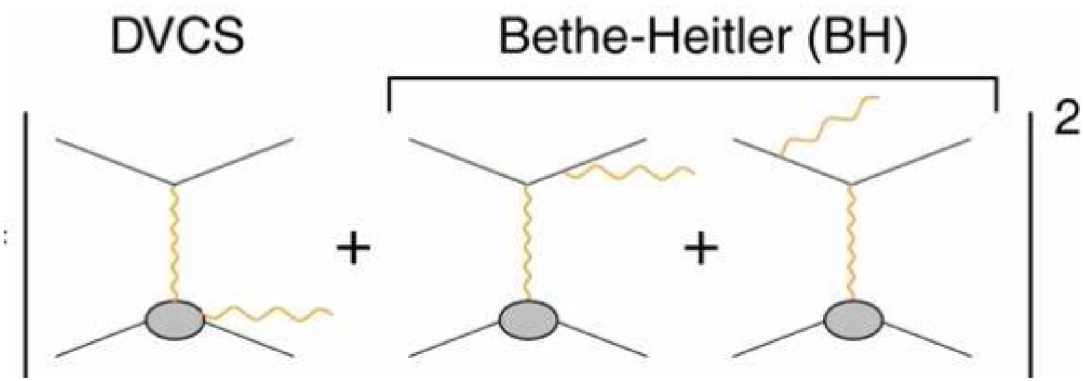
$$t=(p-p')^2=(q-q')^2$$
$$\xi \simeq x_B/(2-x_B)$$
$$x_B=Q^2/2p.q$$
$$Q^2=-q^2=(k-k')^2$$

→ GPD(x,ξ,t): the probability of picking up a parton with momentum x+ ξ and putting it back with a momentum x-ξ without breaking the nucleon.

→ DVCS is sensitive to the Beam-Spin Asymmetry (BSA). It is our observable.

DVCS and Bethe-Heitler processes

◊ **Experimentally,** the DVCS is indistinguishable from Bethe-Heitler (BH) process. Therefore, the measured photon-production cross-section is:



- The cross-section is dominated by BH which is calculable using the elastic form factors
- DVCS signal is enhanced by the interferenece

◊ **For spin zero target and longitudinally polarized electron beam (λ) :**

→ The differential cross-section: $d\sigma \propto |\tau_{\mathrm{BH}}|^2 + \underbrace{(\tau^*_{\mathrm{DVCS}}\tau_{\mathrm{BH}} + \tau^*_{\mathrm{BH}}\tau_{\mathrm{DVCS}})}_{\mathcal{I}} + |\tau_{\mathrm{DVCS}}|^2$

→ The Coherent DVCS (SPIN ZERO → ONE GPD IS NEEDED $H_A(x,\xi,t)$):

$$A_{LU} = \frac{\alpha_0(\phi) * \mathcal{H}_{Im}}{\alpha_1(\phi) + \alpha_2(\phi)\mathcal{H}_{Re} + \alpha_3(\phi)(\mathcal{H}_{Im} + \mathcal{H}_{Re})} = \frac{\sigma^+ - \sigma^-}{\sigma^+ - \sigma^-}$$

$$\mathcal{H}_{Re}(\xi,t) = \mathcal{P}\int_0^1 dx[H_A(x,\xi,t) - H_A(-x,\xi,t)]\,C^+(x,\xi)$$

$$\mathcal{H}_{Im}(\xi,t) = H_A(\xi,\xi,t) - H_A(-\xi,\xi,t)$$

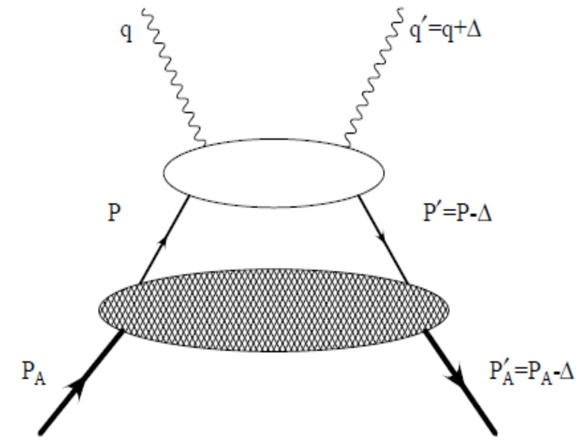
DVCS off nuclei

Nuclear DVCS provides access to two channels:

◊ **Coherent DVCS: $e^- A \to e^- A \gamma$**

→ Study the partonic structure of the nucleus.

→ One GPD is needed to parametrize the structure of the spinless nuclei (^{4}He, ^{12}C, ^{16}O, ...).

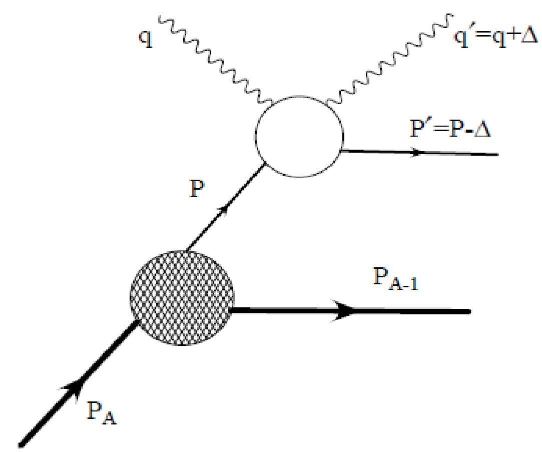


◊ **InCoherent DVCS: $e^- A \to e^- N X \gamma$**

→ The nucleus breaks and the DVCS takes place over a nucleon.

→ Study the partonic structure of the bound nucleons (4 GPDs are needed to parametrize their structure).

→ Study the medium modifications of the nucleons (EMC effect) in terms of GPDs.

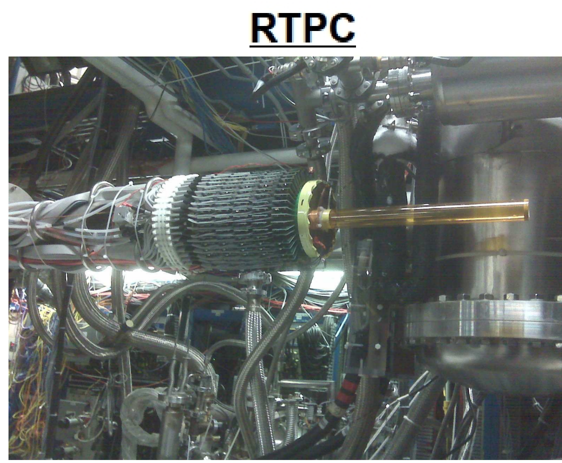


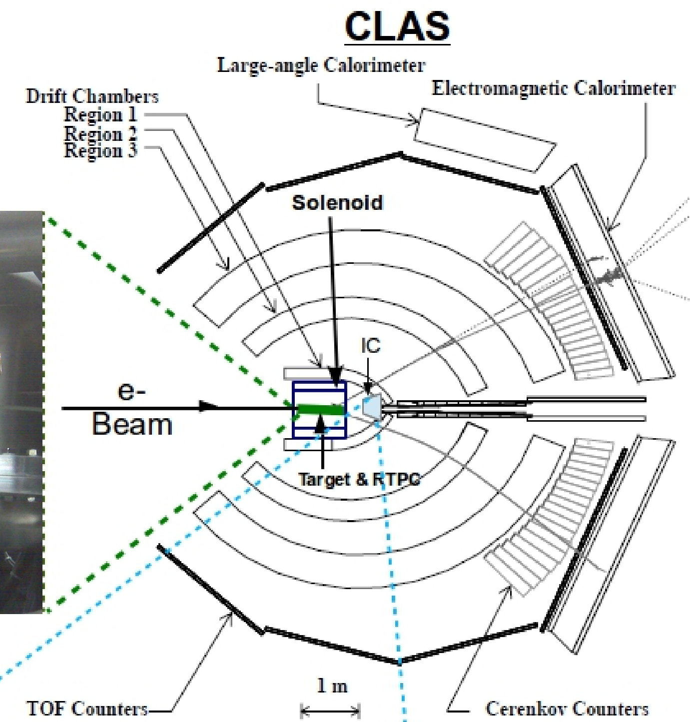
Experimental Setup

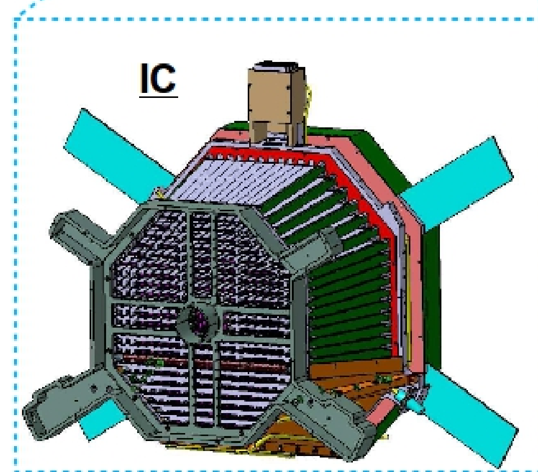
PR-08-024 experiment, Hall B, JLab (Virginia, USA), 2009.

$$e^- \, {}^4He \rightarrow e^- \, ({}^4He/pX) \, \gamma$$

6 GeV,
L. polarized







- CLAS:
→ Superconducting Torus magnet.
→ 6 independent sectors:
→ DCs track charged particles.
→ CCs separate e^-/π^-.
→ ECs detect γ, e^- and n [8º,45º].
→ TOF Counters identify hadrons.

- RTPC: Detects low energy nuclei.

- IC: Improves γ detection acceptance [4º,14º].

- Solenoid: Shields the detectors from Moller electrons.

- Target: ${}^4He$ gas @ 6 atm, 293 K

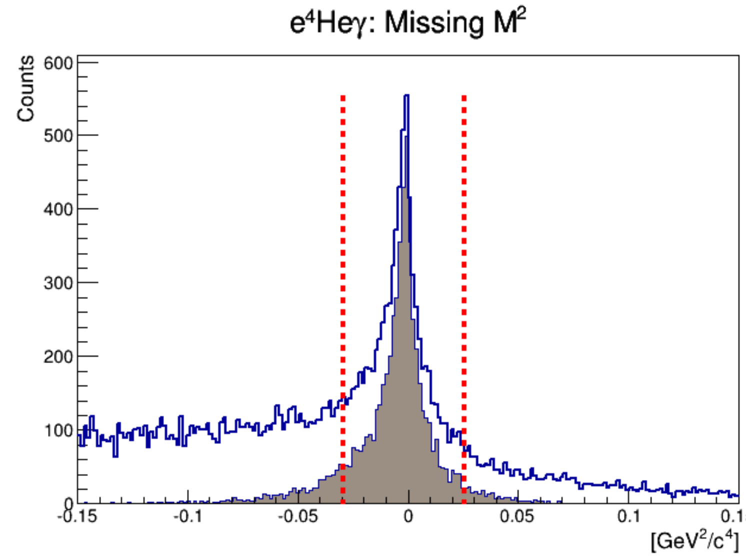
DVCS events selection

We select events which have:

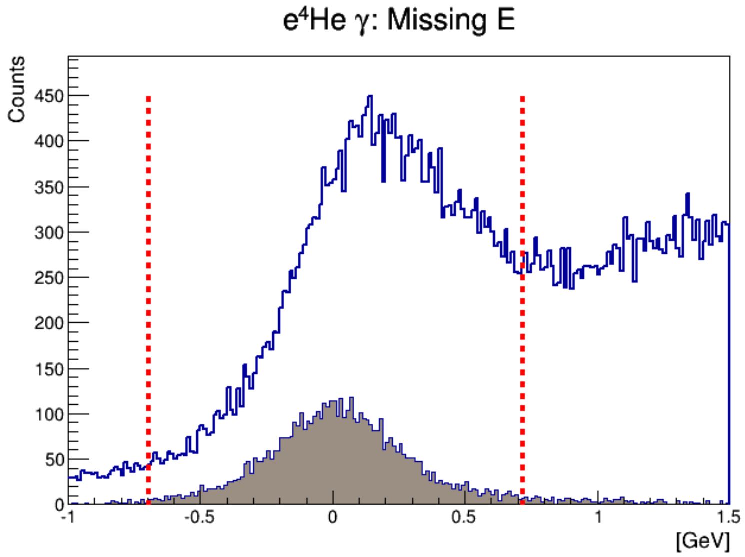
◊ Coherent (InCoherent): Only one good electron, at least one photon and only one good ^{4}He(p).

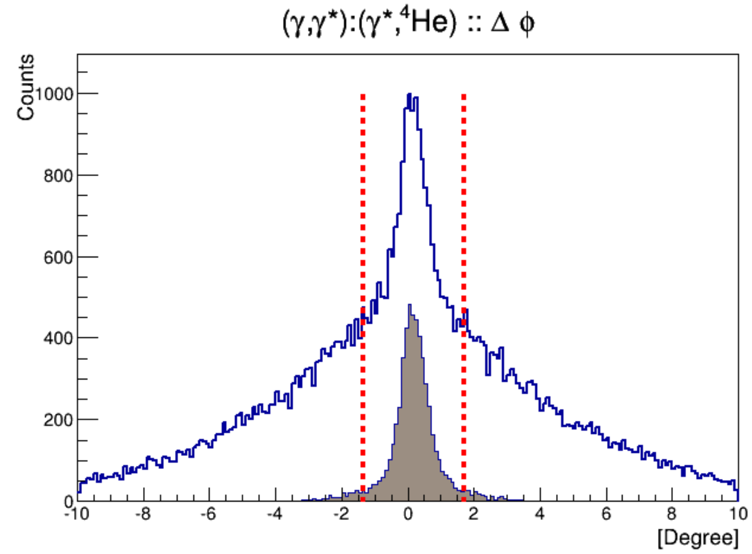
◊ $E\gamma >$ 2 GeV,   W > 2 GeV/c , $(E_b-E_{e'})/E_b <$ 0.85 and $Q^2 >$ 1 GeV^2.

◊ Exclusivity cuts (3 sigmas).



- In BLUE, coherent events before all exclusivity cuts.
- In shadowed BROWN, coherent DVCS events which pass all the other exclusivity cuts except the quantity itself.





Background Subtraction

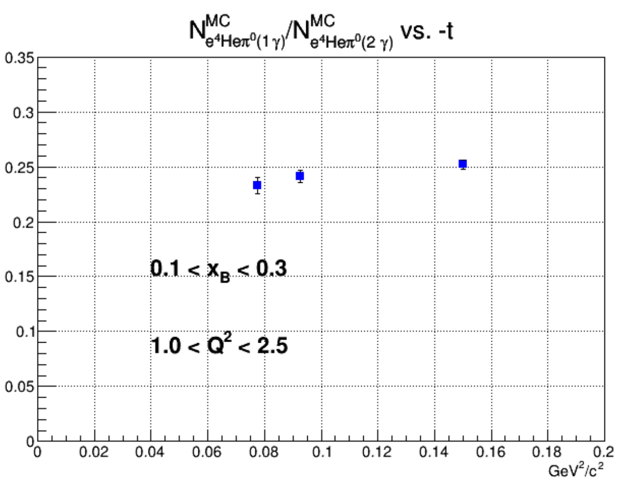
◊ With our kinematics, the main background comes from the exclusive π^0 channel ($e(^4He/p)\pi^0$) in which one photon of the π^0's photons is detected and passed the DVCS exclusivity cuts.

◊ We use simulation to compute the contamination of π^0 to the DVCS channels.

$$\overleftrightarrow{N}_{DVCS/BH} = \overleftrightarrow{N}^{Exp.}_{eHe\gamma} - \overleftrightarrow{N}^{Exp.}_{eHe\pi^0(1\gamma)} = \overleftrightarrow{N}^{Exp.}_{eHe\gamma} - \left(N^{MC}_{eHe\pi^0(1\gamma)} / N^{MC}_{eHe\pi^0(2\gamma)}\right) * \overleftrightarrow{N}^{Exp.}_{eHe\pi^0(2\gamma)}$$

R ($1\gamma/2\gamma$) × Relative yield of $e^4He\pi^0$ = Relative contamination

→ In -t bins (integrated over φ_h, Q^2, x_B):



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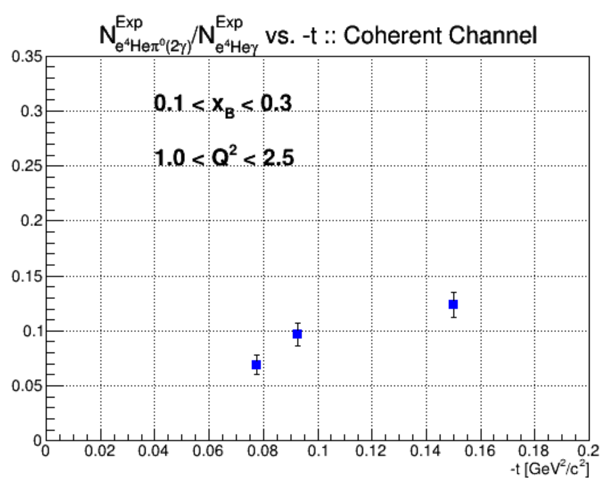

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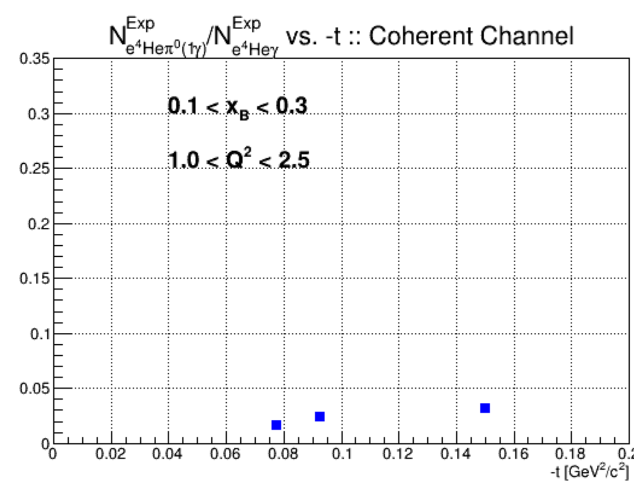


◊ Background yeild ratio ~ 2-4% (8-11%) in $e^-\,^4He\gamma$ ($e^-p\gamma$) DVCS channel.

Coherent ($\vec{e}^{-}$ ^{4}He) beam-spin asymmetries

$$A_{LU} = \frac{1}{P_B}\frac{N^+ - N^-}{N^+ + N^-}$$

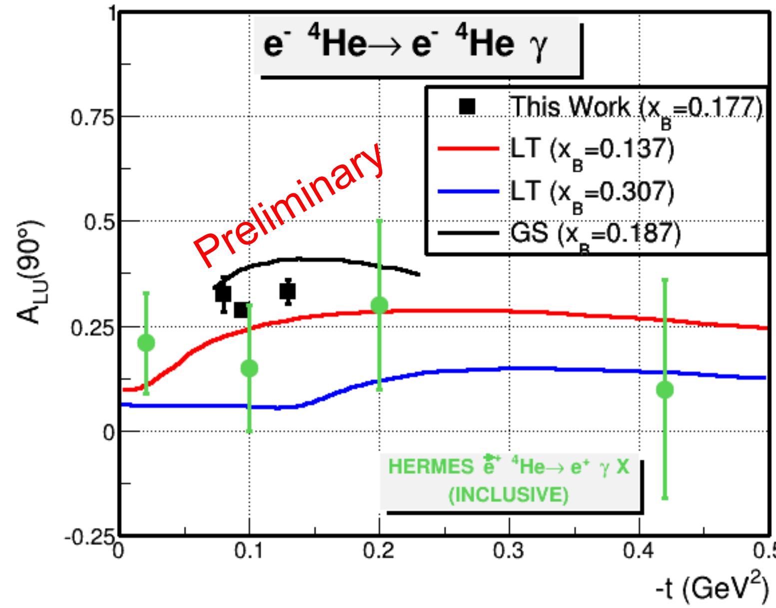
Beam polarization (P_B) = 83%

→ Probed coherent kinematical regions:

$0.06 < -t < 0.2 \rightarrow \langle -t \rangle = 0.100$

$1.0 < Q^2 < 2.5 \rightarrow \langle Q^2 \rangle = 1.488$

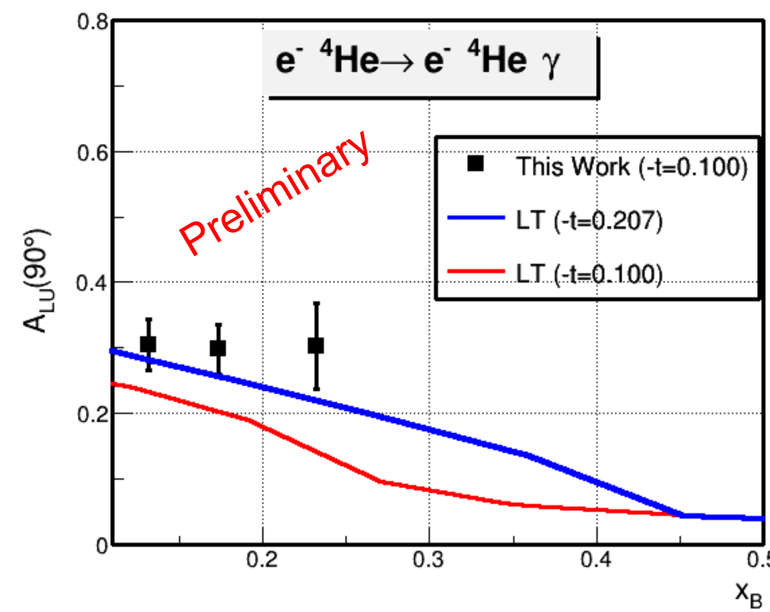
$0.1 < x_B < 0.3 \rightarrow \langle x_B \rangle = 0.177$



- Due to statistical constrains, we constructed 2D bins -t or x_B or Q^2 versus φ
- The A_{LU} signals are fitted with :

$$p_0 * \sin(\phi)/(1 + p_1 * \cos(\phi))$$

- Statistical errors ONLY are shown in our points



→ A_{LU} @ 90° vs. (<-t>/<xB>)

[1] LT: S. Liuti and S. K. Taneja.Phys. Rev., C72:032201, 2005.
[2] GS: V. Guzey and M. Strikman. Phys. Rev., C68:015204, 2003.
[3] HERMES: F. Ellinghaus, R. Shanidze, and J. Volmer. AIP Conf. Proc., 675:303–307, 2003.

Compton form factor (H_A) extraction

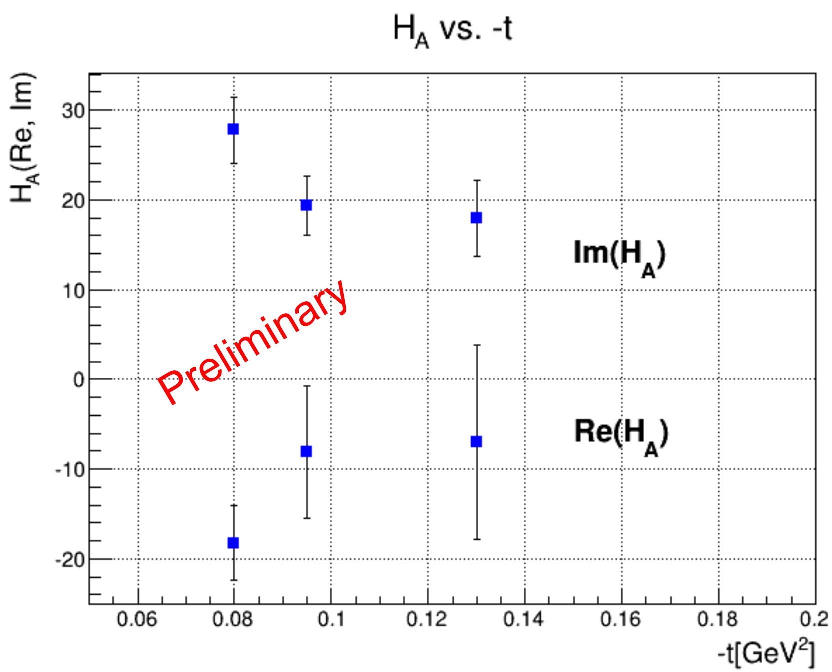
$$A_{LU} = \frac{\alpha_0(\phi) * \mathcal{H}_{Im}}{\alpha_1(\phi) + \alpha_2(\phi)\mathcal{H}_{Re} + \alpha_3(\phi)(\mathcal{H}_{Im} + \mathcal{H}_{Re})}$$

$$\alpha_0 \sim 10^{-2},\ \alpha_1 \sim 10,\ \alpha_2 \sim 10^{-2},\ \boxed{\alpha_3 \sim 10^{-4}}$$

We are not sensitive to this order

$$\begin{aligned}\alpha_0(\phi) &= a\sin(\phi)\\ \alpha_1(\phi) &= b + c\cos(\phi) + \boxed{d\cos(2\phi)}\\ \alpha_2(\phi) &= h + f\cos(\phi)\end{aligned}$$

Negligible



- Using the kinematical calculable factors (a, b, c, h and f) and the fitted coherent

A_{LU} @ 90° vs. <-t>

$$p_0 * \sin(\phi)/(1 + p_1 * \cos(\phi))$$

→ Extracted the real and the imagenary parts of the Compton form factor.

- We have "significant" trends with t and x_B as well.

InCoherent (e^{-}⌈ p) beam-spin asymmetries

◊ Probed kinematical regions:

$0.05 < -t < 2.5$ [GeV²]

$1.0 < Q^2 < 4.5$ [GeV²]

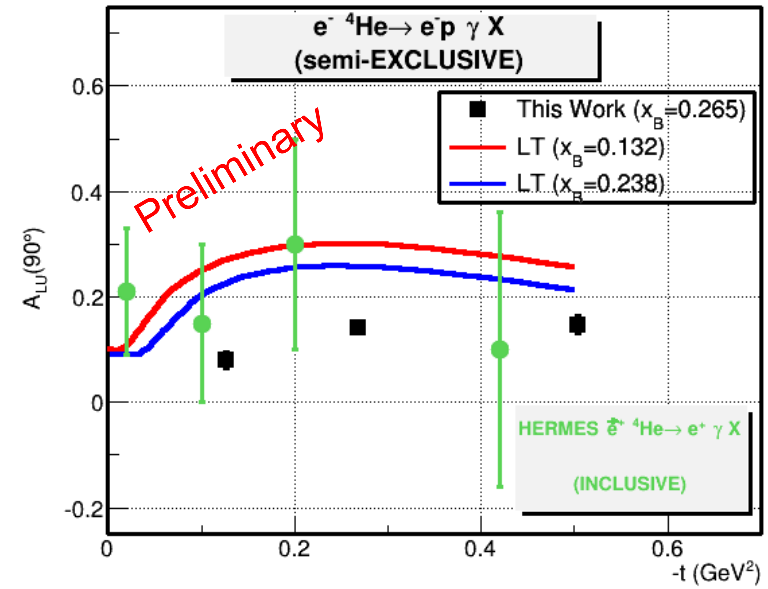
$0.1 < x_B < 5.5$

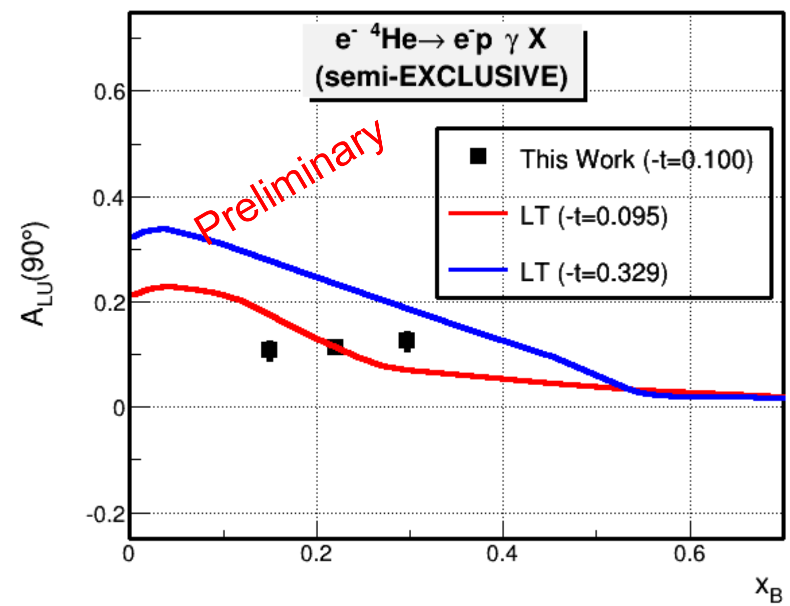
◊ The black points are our measured asymmetries after the background subtraction in which:

- 2D bins ($-t/x_B/Q^2$) vs. Φ
- Fitted with $p_0 * \sin(\phi)/(1 + p_1 * \cos(\phi))$
- Statistical errors ONLY are shown in our points

◊ Theoretical predictions:

- In -t @ x_B=0.132 and 0.238
- In x_B @ -t= -0.095 and 0.326





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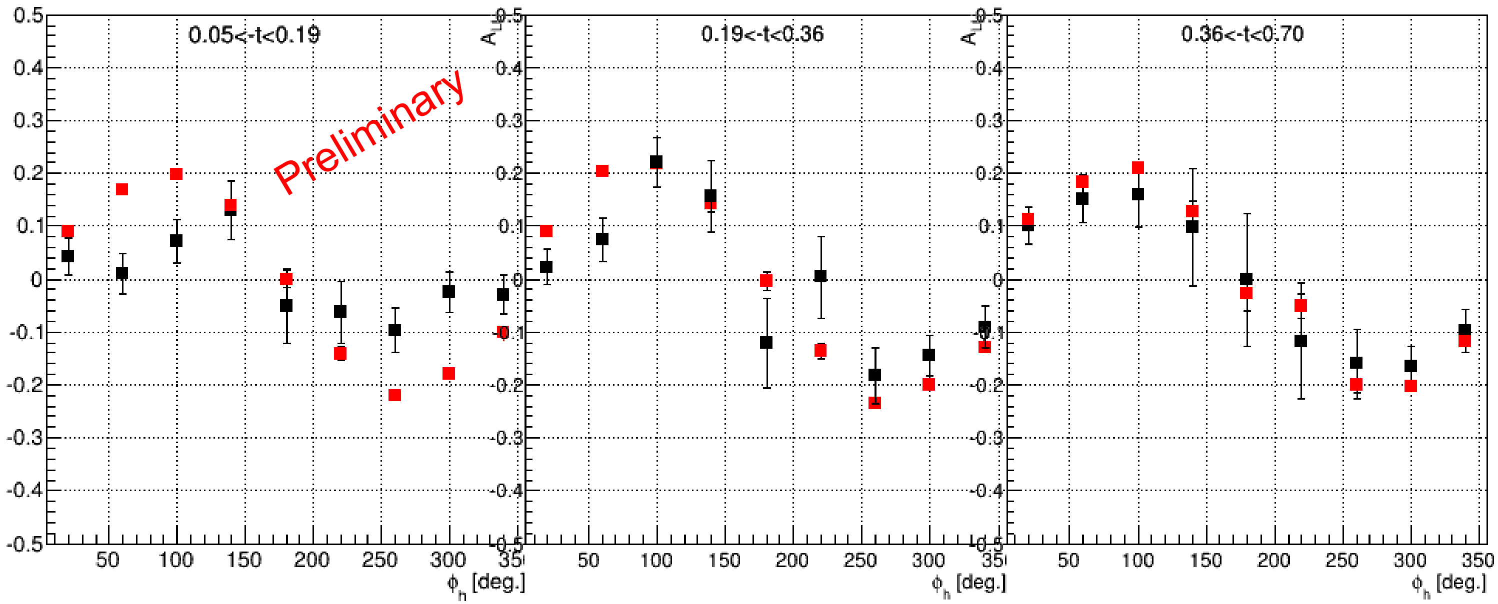
EMC ratio

◊ Possible explanation of the EMC effect:
Modifications of the nucleons themselves in the nuclear medium

◊ We compared between our measured incoherent asymmetries (Black points) and the free proton asymmetries measured in e1dvcs2 experiment (Red Points).

* **Integrated over:**
$0.1 < x_B < 0.55$
$1.0 < Q^2 < 4.5$



◊ At small -t, the bound proton show lower asymmetry than the free one.
◊ At high -t, the two protons show the same trend.

Conclusions

◊ The exclusive DVCS off ^{4}He were measured for the first time with our experiment

◊ Preliminary asymmetries were extracted and good agreement With the theoretical predictions have been observed

◊ With our available statistics, the bounded proton has shown a different trend comparing to the free one

◊ Perspectives:
  → Final results soon
  → Proposing a new ^{4}He DVCS experiment with JLab upgrade.

Thanks for your attention